# VEPP-4M OPERATION AT LOW ENERGY*

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### *Abstract*

During the last few years the $e^+e^-$ collider *VEPP-4M* was operating in the low energy range E = 1.5–2 GeV in order to study $\psi$- and $\tau$-physics. Recently another measurement of the $\psi$- and $\psi'$-meson masses was performed at *VEPP-4M* with the detector *KEDR*, and the measurement accuracy was 3 times as high as that of the previous precise experiments. The paper covers the precise energy measurement results obtained at *VEPP-4M* as well as other issues of the accelerator physics including the low energy luminosity, influence of wigglers on beam parameters, experimental non-linear beam dynamics study etc.

## INTRODUCTION

Currently VEPP-4M continues the earlier experiments and scan *$\psi'$(3686)* in order to replenish the statistics of our previous experiment [1] and *$\psi''$(3770)* to measure its mass with accuracy 3 to 4 times as good as that cited in the PDG table and to study $D^{\pm}$ and $D^0$-mesons.

A low energy range is not typical for *VEPP-4M*, which has been designed to operate at 5-6 GeV, and low synchrotron radiation damping causes different problems for the machine performance and beam dynamics. To increase the radiation damping rate, two 3-pole wigglers are installed symmetrically relative to the interaction point but the strong influence of the wiggler field over the beam motion is a matter of a special study.

Precise energy calibration by the resonant depolarization technique is a merit of *VEPP-4M* operation and in spite of the moderate (as compared with the modern factories) luminosity our facility still seems to be suitable for some classes of HEP experiments that require accurate measurement of particle energy.

Results of the polarization experiments, facility performance at low energy, non-linear beam dynamics experiments and other relevant issues are discussed below.

## PRECISE ENERGY MEASUREMENT

### *Energy measurement at VEPP-4M*

A method of high precision measurement of the beam average energy by the spin depolarization technique was proposed and developed at *BINP* in the 1970s [2]. At present, realization of this method at *VEPP-4M* provides relative accuracy of the beam energy calibration at a record level of $\sim 10^{-6}$.

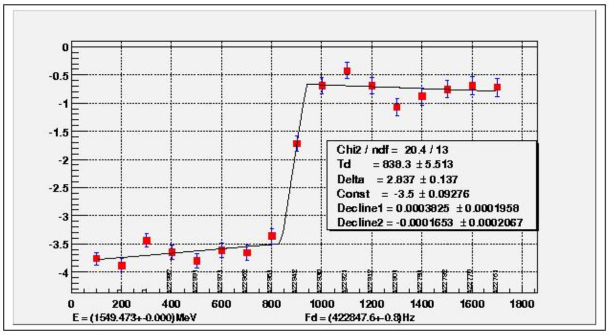

Figure1: The change of the intrabeam scattering count rate.

The electron beam polarizes in the 2 GeV booster storage ring *VEPP-3* and two bunches (polarized and reference) are injected one after another into the *VEPP-4M* vacuum chamber. RF voltage applied to the exciter electrodes sweeps some frequency range close to the spin precession frequency, and special counters inserted inside the vacuum chamber registered Touschek electrons. Since the intrabeam scattering depends on the particle spin, the ratio $1-\dot{N}_1/\dot{N}_2$ increases step-wise (see Fig.1) when the test bunch is depolarized and the frequency of the RF voltage gives us the beam energy [3].

The energy measurement precision $\Delta E \approx \pm 2$ keV is defined by the depolarizer frequency spread ≈5 Hz. To achieve such a tolerance several technical tasks had to be solved, including careful adjustment of the depolarizer, providing long-term stability of the main magnetic elements at the level of ±5÷20 ppm and suppression of the main PS noise down to 3 ppm at 50 Hz etc.

In spite of temperature stabilization of the ring magnets and tunnel, the main factor influencing the beam energy drift is the cooling water temperature (the relative energy deviation is –40 ppm/°C).

We carefully studied all the essential factors giving a systematic error of particle mass measurement, including

1. The difference between the electron and positron beams. A direct measurement has shown that it does not exceed 2±4 keV.
2. Since the electrostatic separation of the $e^+e^-$ bunches is off for the luminosity run while it is on during the energy calibration, we have measured the separation influence over the beam energy and obtained <4 keV.
3. The horizontal orbit instability during the experimental run can cause an uncontrollable energy drift between two calibration points, so we have investigated the COD impact on the beam energy. It can be shown that the rms distortion of the horizontal orbit $\sigma_x$ results in the rms energy shift $\sigma_E$ (due to the orbit lengthening) according to

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$$\sigma_E \sim \sigma_x \frac{2\sqrt{2}\sin \pi\nu_x}{\alpha L}\frac{\overline{\eta}}{\overline{\beta}_x},$$

where $L$ is the orbit length, $\alpha$ is the compaction factor, $\nu_x$ is the horizontal betatron number and $\overline{\eta}$ and $\overline{\beta}_x$ are the mean values of the dispersion and betatron functions. An estimation, corresponding well to the measurement results, shows that to reach the required value $\sigma_E \sim 5\times10^{-6}$ the drift of the horizontal orbit during the experimental run time should not exceed $\sigma_x \leq 0.1$ mm.

4. Since the lattice functions in the interaction point depend on the bunch energy, the maximum of luminosity does not correspond exactly to the average beam energy. The sextupole magnet tuning to achieve the total systematic error in the resonance mass determination around 5 keV minimized this effect.

### *Energy measurement in VEPP-3*

One of the major experimental tasks of the *VEPP-4M* in the nearest future is the study of the $\tau$-lepton at its production energy threshold (1777 MeV). This value is close enough to the strong spin integer resonance $\nu_s$=4 (1762.6 MeV) and detailed study of the beam polarization behavior is necessary in this region to ensure effective energy calibration.

A possible scenario includes the beam polarization in the *VEPP-3* storage ring exactly at the experiment energy and its injection into the *VEPP-4M*. Therefore, the important question is the energy dependence of the *VEPP-3* beam polarization degree. However, the Touschek scattering rate is rather low for *VEPP-3* because of the large beam size and we can not use the traditional polarization measurement technique.

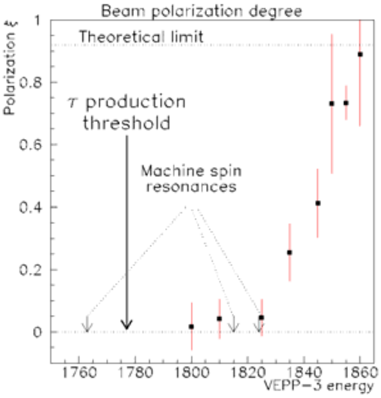

Figure 2: VEPP-3 beam polarization degree.

New methods base on the Möller scattering of the polarized electron of the beam on the polarized internal gas target. The angle distribution of the scattered electrons depends on the polarization degree, which thus can be measured by detector system. The Möller polarimeter includes a polarized deuterium jet target ($5\times10^{11}$ atoms/cm$^2$), a zero-integral vertical magnet producing the alternating magnetic field and controlling the target polarization direction and two counters placed above and below the median plane.

The method has allowed us to measure the *VEPP-3* beam polarization degree as a function of energy (Fig.2). One can see a significant reduction of polarization in the tau energy range. According to this measurement, a different scenario when electrons are always injected to the *VEPP-4M* at an energy of 1850 MeV and then are decelerated to the experiment energy is chosen.

## LOW ENERGY LUMINOSITY

Because of the strong luminosity dependence on the beam energy $L \propto \gamma^4$, reduction of energy is a serious problem for collider performance. Recently the two-bunch operation mode was settled at *VEPP-4M*, which gave us the peak luminosity value twice as large as that in the 2001 $\psi$- and $\psi'$-scanning. Besides, we hope to increase the present number ($10^{30}$ cm$^{-2}$s$^{-1}$) by a factor of 1.5 via an additional "adiabatic" tuning of the machine, shift of the tune point (8.54, 7.57) closer to the half-integer resonance and reduction of the $\beta^*_z$ from 5 cm down to 2.5 cm.

Another prevailing method to enhance the luminosity is application of wigglers, which provides an increase of the horizontal emittance and hence the current threshold limited by the beam-beam effect. Two 3-pole 1-m dipole wigglers with a 1.8 T magnetic field amplitude are installed on *VEPP-4M* symmetrically realative to the interaction point. Simulation with the LIFETRACK computer code [4] promised us an additional factor of 2 in the luminosity enhancement as compared to the wiggler switched-off mode. However, the experimental wiggler study run gave us only 1.7 instead of 2.0, which corresponds to $\xi_y \approx 0.046$ and $\xi_x \approx 0.02$ and the beam lifetime $\tau$ = 1.3 hour. This fact has stimulated our interest to a more careful study of the beam motion with the wigglers introduced.

## DIPOLE WIGGLERS ON VEPP-4M

Wigglers, which are required for emittance control, can influence the beam in following ways:

- Change of the synchrotron radiation damping parameters.
- Distortion of the linear optics characteristics. In our case for $E$=1.8 GeV and a wiggler field amplitude of 1.8 T, the maximum $\Delta\nu_z \approx 0.09$ and the betatron function beating reaches ~50%.
- Nonlinear perturbation of particle motion and reduction of the beam stability area.

The linear lattice distortion is recovered by the local quadrupole scheme (beta beating) and global quadrupole correction (tune shift). A resulting deviation of the betatron functions in the arcs is less 10%. However, measurement in the corrected lattice still shows a reduction of the dynamic aperture (Fig.3) that can cause the luminosity limitation.

Simultaneously with the dynamic aperture reduction, the wigglers provide serious change of the nonlinear detuning coefficients (see Table 1) defined as

$$\Delta\nu_x = C_{xx}A_x^2 + C_{xy}A_y^2,\ \Delta\nu_y = C_{yx}A_x^2 + C_{yy}A_y^2.$$

Table 1 shows that the wiggler field introduces high vertical and coupling coefficients.

Table 1: Nonlinear detuning coefficients.

| | | $\times 10^4$, mm$^{-2}$ | | | |
|---|---|---|---|---|---|
| Wig. | SEOQ (A) | Cxx | Cxy | Cyx | Cyy |
| Off | 0 | 3 | –0.1 | 1.2 | –2 |
| On | 0 | 5 | 3 | 10 | 8 |
| On | +9 | 5 | 1 | 3 | 2 |

After some study we revealed the octupole magnets SEOQ ($\beta_x$≈50 m, $\beta_x$≈50 m), which reduce the wiggler induced nonlinearly (Table 1) and practically compensate the dynamic aperture shrinking (triangles in Fig.3).

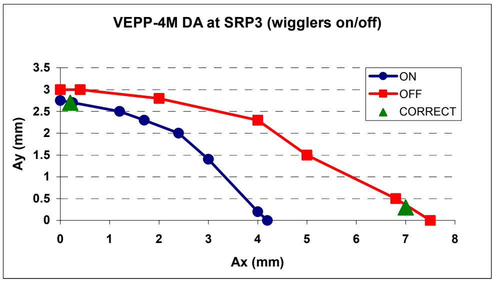

Figure 3: Wiggler on/off dynamic aperture.

## NEW BEAM DIAGNOSTICS

Effectiveness of collider tuning depends primarily on the beam diagnostic system feature. In order to study dynamic beam effects (especially those related to the beam-beam interaction and instabilities), two new optical devices were developed and installed on *VEPP-4M*.

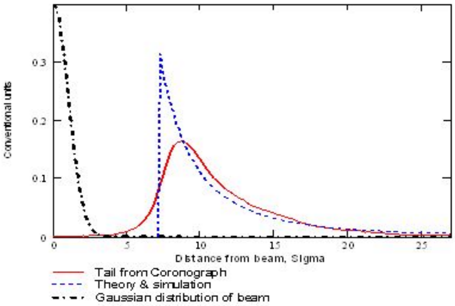

Figure 4: CCD coronograph tail plot.

In order to investigate the transverse tail (beyond 7σ) distribution of particles, a "coronograph" has been manufactured and tested at the beam. The main idea of such a device is similar to that applied to study the Sun corona area. A source of radiation is obscured by an artificial Moon, while the tail areas are focused at the CCD camera so that to provide a relative accuracy of the measured signal of $10^{-6}$.

Fig.4 demonstrates the coronograph plot in comparison with the tail distribution simulation [5] and trivial Gaussian profile that is seen to differ much from the actual particle density. A sensitivity of the coronograph allows one to detect a signal from as few as 1000 electrons circulating in the accelerator vacuum chamber.

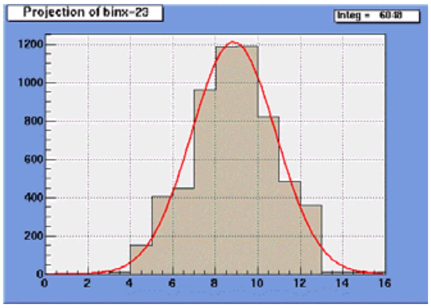

Figure 5: Single-turn particle distribution.

Another promising beam diagnostic tool is a fast multi-anode photomultiplier tube installed on *VEPP-4M*. This system, which bases on the Hamamatsu R5900-L16 16-channel linear array with the 0.8×16 mm$^2$ anode area, provides turn-by-turn measurement of the transverse beam distribution during $2^{17}$ revolutions. Fig.5 depicts a single-turn particle distribution in the electron beam.

Possible applications of such a diagnostic device can include fast instability study, injected beam evolution study, precise tune measurements etc.

## CONCLUSION

A possibility of precise energy measurement provides new attractive features for the HEP experiments on *VEPP-4M* in the range of the ψ, the τ and charm production. The experiment on the accurate measurement of the τ mass that will start next autumn requires careful study of the spin dynamics distorted by the integer $\nu_s = 4$ and combined spin-orbit resonances. For this purpose we plan to use polarimeters based on Touschek and Möller scattering of polarized electrons. Dipole wigglers is expected to allow increasing of luminosity. New optical diagnostic devices were developed and tested at the beam.

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